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Research Establishment Risø, Roskilde

Publication date:
1973

Document Version
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Risø-M-1632

Danish Atomic Energy Commission

Research Establishment Risö

ELECTRONICS DEPARTMENT

ANNUAL REPORT 1972

August 19[illegible]

A. E. K. Risø

Risø-M-1632

Risø-M-1632

Title and author(s)	Date August 1973
Annual Report 1972	Department or group Electronics
	Group's own registration number(s) R-7-73
pages + tables + illustrations	

Abstract

Topics are selected from research in systems techniques, nuclear geophysical methods, and laser techniques. The report also reviews development of instrumentation for Risø experiments. Publications issued during the period are listed.

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Abstract to

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ISBN 87 550 0209 9

CONTENTS

INTRODUCTION

The electronics department covers a broad spectrum of activities from service on standard electronic equipment to research in geophysics, process control, and lasers. Most efforts in the department are centred around the development, building, and maintenance of the instrumentation used by the different research groups at Risø.

The following pages give short accounts of selected topics, projects of mainly internal relevance having been left out.

The geophysics group continued mineral prospecting work in Greenland, using airborne equipment. A facility was deveoped at the DR 2 reactor for neutron activation analysis of geologic samples. Radio isotope excited X-ray fluorescence was used to analyse manganese material from the Pacific Ocean.

Work in the systems group aims at the control and instrumentation of nuclear power plants. Main topics are: the structure of control systems, human factors engineering of the control room function, system simulation, and reliability evaluation methods.

Laser technique is studied, especially laser anemometry. The scattering from liquids was treated in a general form, and a project was initiated on telemetering of wind velocities with lasers.

Process instrumentation work was dominated by the instrumentation of the cold-neutron source at the DR3 reactor, and by participation in the development of a tube inspection system. Other projects in the year were: heat transmission experiments, thermodynamic flow measuring, and water film measurements.

The research instrumentation group divided its efforts among several topics: CAMAC work, noise studies, the neutron spectrometer TAS6, and meteorological studies as well as pulsed radiolysis, plasma physics, and neutron activation analysis.

DETERMINATION OF URANIUM AND THORIUM BY MEANS OF NEUTRON ACTIVATION ANALYSIS

Equipment has been installed at the research reactor DR 2 for the determination of uranium and thorium in geologic materials. The method used consists in a counting of the delayed neutrons which are emitted as a result of the fission of U^{235}, U^{238}, or Th^{232}.

The equipment comprises a pneumatic sample-transfer system, a cell for handling irradiated samples, and a neutron detector. The irradiation position is very close to the reactor core. With a normal reactor power of 5 MW the thermal and the fast neutron fluxes are 10^{13} and $2 \cdot 10^{12}$ $n/cm^2/s$ respectively. The samples are typically irradiated for 60 seconds each. A sample, usually about ten grams of a powdered rock specimen, is filled into a 7 ml polyethylene ampoule which is heat-sealed and placed in a "rabbit". After the sample has been irradiated, the "rabbit" automatically returns to the handling cell. At this stage the analyst opens the "rabbit" and drops the ampoule into a vertical steel tube which passes through the centre of the neutron detector. Fig. 1 shows this operation.

The neutron detector is a cylindrical, water-filled steel tank in which nine BF_3-filled proportional counters are vertically mounted in the shape of a ring. The detector is surrounded by a 10 cm-thick layer of boron-impregnated plastic for suppressing the background count-rate. About 60 background counts are registered per minute. A counting of delayed fission neutrons automatically begins 20 or 24 seconds after the sample leaves the reactor. The counting normally lasts one minute, after which the number of counts, the irradiation time, the decay time, and the counting time are printed on a Teletype printer.

A single analysis comprises four or six single measurements of the sample. Half the irradiations are made with a "rabbit" which is lined with a sheet of cadmium for removal of the thermal reactor neutrons in the determination of thorium. Calibration measurements are made using standard samples prepared from precipitation of dissolved uranium and thorium salts on silica gel. The unfiltered reactor flux results in 750 counts per microgram uranium and 7 counts per microgram thorium. The cadmium ratio is 22 for uranium and 1.0 for thorium.

About sixty single measurements can be made in one afternoon, corresponding to about eight U-Th analyses per day. The data are reduced by means of an algol program, "NEUFAX", for use with Risø's B-6700 computer.

The technique is at present being used for studies of the abundancies of U and Th in metamorphic rocks belonging to the old Pre-Cambrian of central West Greenland. These rocks have generally less than 0.5 ppm U and 3 ppm Th.

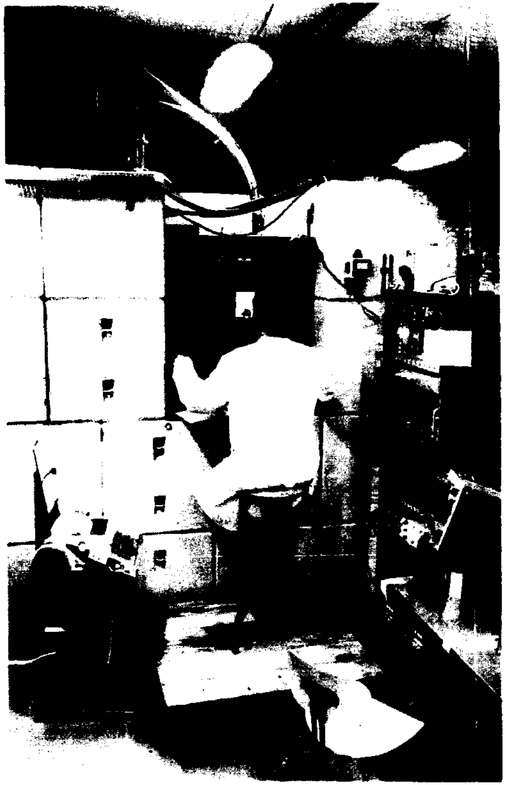

Fig. 1. Handling of neutron-activated rock sample at research reactor DR 2.

AERORADIOMETRIC SURVEY TECHNIQUES

1. Purpose and Status

About two years ago the Geological Survey of Greenland and the Atomic Energy Commission began common research on the geology of thorium, uranium, and potassium in Greenland. It was decided to investigate during the next five years the abundancies of these three radioelements in central East Greenland up to 76^{o}N. This part of Greenland is characterized by, among other things, formations from the Mesozoic. Since large and partly inaccessible areas were to be explored, surveying by means of airborne gamma-ray spectrometers was considered the most expedient technique.

In the summer of 1971 detailed aeroradiometric surveys were made over parts of Milne Land and Liverpool Land, and over an area west of the Schubert Valley. Reconnaissance flights were made over Jameson Land and over the area surrounding Mesters Vig. A Dornier-28 twin-engine aircraft was used, and gamma-spectrometric data were recorded by means of a Nuclear Enterprises four-channel spectrometer system. This system comprised two 4" thick x 6" diameter NaI(Tl) crystals, four ratemeters and a multi-pen galvanometer recorder which registered the ratemeter signals and the terrain clearance. The measurements lasted 60 hours and were carried out at an average terrain clearance of 100 feet and a ground speed of about 100 km/h.

In the course of 1972 all data were digitized and transferred to magnetic tape. This operation was extremely tedious as the strip-chart records had to be traced over with India ink before they could be digitized by means of an optical curve follower. An Algol program for Risø's B-6700 computer was written for automatic drawing of final flight records on a Calcomp plotter. This program has options for background subtraction, height compensation, and "spectral stripping". The approximate "stripping ratios" were determined experimentally from measurements on four large concrete calibration slabs located at Risø.

An example of a flight record is given in fig. 2 which shows height data and corrected aeroradiometric data from a 55-km-long flight path over Jurassic sandstones on eastern Milne Land. Two thorium anomalies (A and B) are observed. Ground investigations have shown that these result from a mineralization of monazite. An apparent anomaly (C) on the U/K curve is clearly a false one. It must be ascribed to an erratic data point in the stripped 1.46-MeV count rate.

On the basis of our initial experience with aeroradiometric survey techniques we decided to improve our airborne instrumentation in regard to

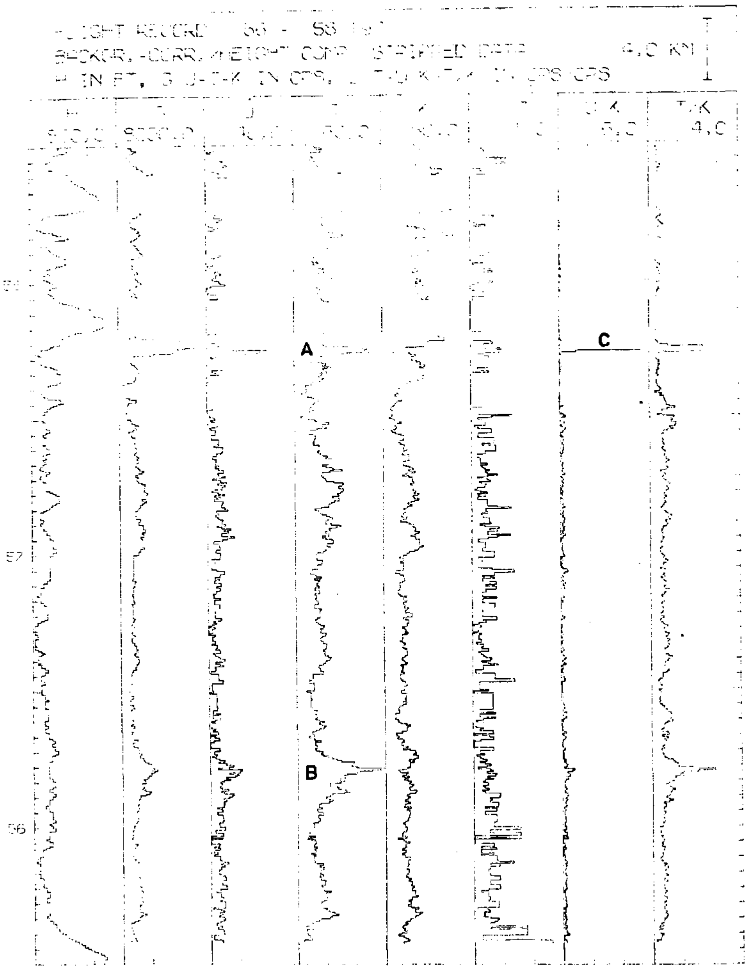

Fig. 2. Aeroradiometric profile from Milne Land, East Greenland.

H: Terrain clearance
G: Count rate, 0 3 - 3,0 MeV
T: - - , 2,0 - 3,0 -
U: - - , 1,6 - 2,0 -
K: - - , 1,3 - 1,6 -

sensitivity and data-collection performance. The improved equipment, which is described below, is going to be test-flown and used in East Greenland in the summer of 1973.

2. Advances in Instrumentation

The new airborne instrument is as the one used for the measurements mentioned above a four-channel gamma-ray spectrometer.

The detector comprises six 4" thick by 6" diameter NaI(TL) crystal--photomultiplier assemblies contained in a temperature-stabilized housing. The increased detector volume will allow a safer terrain clearance during the measurements. The six comparatively small crystals were chosen instead of one or a few bigger one because this will ensure that results are obtained even in case of crystal failure.

Data recording is on punched paper tape. Once started, the instrument will automatically perform the measurements and record the counts from the four channels together with the terrain clearance. For every 32 measurements the data, the time of the day, and some other parameters are punched. The total radiation counts and the terrain clearance are also recorded on a strip chart recorder in order to make a preliminary assessment of the results possible. To have a common time reference for the crew the data and the time of the day are shown on three numeric displays together with the terrain clearance. The flight tracks will be recovered by phtographing the overflown landscape and one of the displays with an automatic 35 mm camera. Sampling times in the range 1 - 64 seconds may be selected.

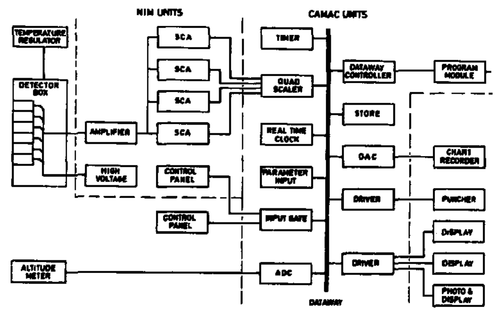

Fig. 3. Block diagram of the instrumentation.

Fig. 3 shows a block diagram of the instrumentation. The greater part is built from standard instrumentation modules, NIM units for the analog part and CAMAC for the control and data-handling parts.

The system is controlled by a programmable controller with a diode matrix program store. After each measurement the contents of the scalers are transferred to a temporary store, and a new measurement is started immediately. During this new measuring period the counts from the previous measurement are punched together with the terrain clearance digitized by an analog-digital converter (ADC).

In addition to the measuring procedure described above programs for setting the real-time clock, and for testing and adjusting the measuring channels may be selected by a switch on the control panel.

ANALYSIS OF CONTROL TASKS IN A POWER PLANT UNIT

Introduction

The work is part of a programme initiated in 1970 in co-operation with the Danish power company I/S Vestkraft (VK) with the purpose of providing a realistic foundation for the development of methods in the fields of applied reliability technique and evaluation of the role of the control room operator. These topics need systematic descriptions of the control tasks both in analysis--oriented problems such as power reactor safety analysis and by synthesis of control systems in a design procedure. Particularly computers in control systems present to the designer an evolutionary step, where in many respects he cannot make extrapolations from preceding experience. A modern oil-fired power plant is attractive as an analysis object since the principles and algorithms used in power plant control have reached their form as a result of evolution over a long span of time.

Analysis, calssification, and description of the control tasks in the VK plant were in 1972 used as basic information for the development work mentioned in a later chapter on "Methods for Description of Complex Systems". The work is being carried out in close interaction with the study of actual computer-based systems and their reliability.

The knowledge obtained during the general control task analysis was a prerequisite of an analysis of the control room operators' information requirements during a boiler start-up. The result of this task analysis was used for the working out of a proposal for computer-controlled displays as a substitute for the conventional displays. This work is described in the following.

A proposal for a nonconventional alarm display was worked out, aiming at a quick identification of some main alarm characteristics. The proposal is elucidated in a later chapter on "Alarm Presentation".

Analysis of the Control Room Operators' Information Requirements During Boiler Start-up. Proposal for Computer-controlled Displays

The purpose of this work was to describe and classify the operators' working situations in a real-life typical power plant in order to gain experience with methods and procedures for extraction of task information from the operators themselves, and to study how a computer-controlled display could support the working situations found.

The boiler start-up was followed in the control room and the operators provided tape-recorded verbal descriptions during their manoeuvres. A preliminary analysis of this material was discussed with the operators and other members of the plant staff.

Various experiences were gained from this phase concerning the information contents of the tape recordings and their processing, types of documentation and other support for the discussions and the discussions themselves, specific wishes and proposals for improving the displays, different operators' choice of different, however equivalent, procedures for the same task, the influence from the preceding overhaul period which makes each start-up differ from the others. A proposal for a computer-controlled display was worked out, using the before-mentioned analysis as a basis. The proposal is rather detailed to ensure a degree of concreteness notoriously necessary to support discussion with the users, and also to introduce some viewpoints in the discussion with designers of displays.

Already during preparation of the preconditions it became evident to how great an extent the introduction of advanced displays is linked together with topics such as

distribution of tasks between operators on the shift,
indication of abnormalities and integration of this in the displays for normal situations,
the operator/display interaction during plant manoeuvres and data selection.

The work indicated a general need of a systematic approach and criteria for suitability in this field.

ALARM PRESENTATION

When presenting alarms on a CRT-screen in a control room one often resorts to the recording of a chronological list of messages. The list may be automatically updated, and special arrangements are made to handle overflow (paging etc.).

This solution is usable when alarms are infrequent, and if time relations are essential to the operator. However, fairly often the lists are filled up and one looses the general view. In that case a more condensed presentation may be preferable to the list. During the very first stages of alarm identification, different non-chronological structuring of the presentation can be advantageous. Alarms may be arranged according to plant geography or plant circuits. Perhaps a tree diagram for a sequential control algorithm might form the basic pattern. The intention is to stress that there are other structures for presentation than the chronological sequence recording, especially when the plant may incorporate a thousand alarm points.

We have sketched a set of displays for alarm presentation, using the power plant "Vestkraft" as an example. The proposals range from different computer-controlled arrangements of printed "labels" on the screen, to two symbolic presentations. Fig. 4 is part of the most concentrated symbolic proposal; here we represent an alarm by one or two letters and use its position in the screen pattern as an essential part of the message identification.

A characteristic basic pattern is made by irregular figures representing plant components (feed pump, preheater, magnetizing circuit, etc.). The shape of each figure results from alarm characteristics such as prewarning, warning, membership of component subsystems etc., and should support the recognition of the individual alarm. The basic picture composition, however, is intended to follow the main functional relations in the process.

In fig. 5 the alarms are represented by particular symbols, the size of each corresponding to six letters. Symbols belonging to the same plant component are placed inside a rectangular field reserved for this component; the rectangles utilize the screen area completely. The picture is now structured according to plant geography.

Four presentation modes have been implemented on a CRT experimental facility. The presentation will be studied by simulation, utilizing real alarm logging data from "Vestkraft". The experiment is expected to initiate discussions with engineers and operating personnel from Danish power plants. The work will serve as a pilot study to formulate more specific problems in alarm communication, and this will contribute to more systematic design of alarm systems.

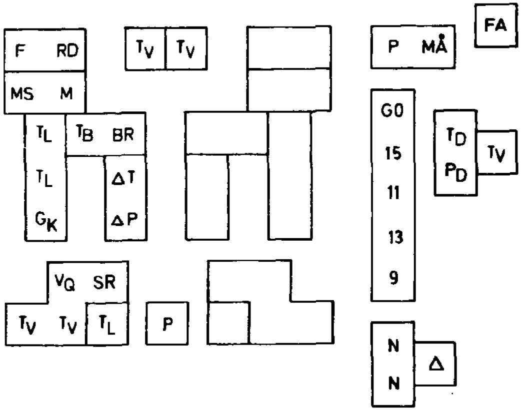

Fig. 4. Sample from alarm presentation with functional arrangement of the signals

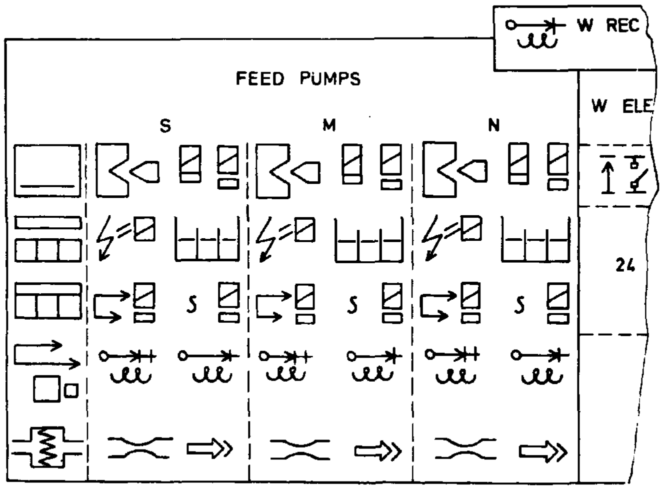

Fig. 5. Alarm presentation with symbols arranged after plant geography

METHODS FOR DESCRIPTION OF COMPLEX SYSTEMS

Purpose

Control systems for power plant are extremely complex, consisting of components for control during normal operation, protective circuits, and components for sequence control. The operator and his operational procedures provide an additional degree of interconnection and complexity in the system.

The equipment available for automation of control, and the possibilities for using this equipment, are changing very rapidly. If this equipment is to be used effectively and safely, it is important to understand the different functions performed by the control system, and to be able to check in a reasonably systematic manner that the functional requirements are met by a new control system design. It is particularly important to be able to describe both the functional objectives and the design for a controller, and to determine the reliability with which the objectives are met.

A major step in describing complex control systems has been to treat the description on three levels

1 functional
2 algorithmic
3 implementation

A functional description indicates the result that the controller is trying to achieve, and generally consist of several parts. For example, one objective in a power plant is, during normal operation, to hold the output power, frequency, and voltage constant, while minimising the costs of fuel used.

An algorithmic description gives the mathematical relations actually obtained in practice, between the inputs and outputs of a control system. If the controller is well designed the result of applying the outputs to a plant will be to satisfy approximately the control system objectives. The relation between the functional and algorithmic description is not straightforward. It depends on the heuristic rules used by the control system builders, and represents the essence of control system design.

An implementation description of a control system indicates how the algorithmic description is mapped onto hardware.

Some functional objectives may be achieved by the performance of several algorithms, each capable of performing independently. This is especially true for protective circuits, where redundancy is common. Similarly, several algorithms may be mapped onto one piece of equipment, for example, a multiprogrammed computer. For reliability purposes, it is important to know when several critical objectives are dependant on one piece of equipment.

The division into functional, algorithmic, and implementation domains is important, since it enables changes in control philosophy to be distinguished from minor changes in hardware. It goes a long way to clarifying the confusion arising from the direct applications of general systems theory.

Progress in 1972

A further step has been made by describing the algorithmic structure of a control system as interconnected subsystems. The subsystems are described by their inputs and outputs as functions of time, and the mathematical relation between these inputs and outputs. In this way, a large body of systems theory, available in published litterature, is made available for practical analyses. Several aspects of such theory have been studied, and should prove of value, provided that sufficiently detailed descriptions of practical control systems can be obtained.

An algebraic method has been developed for describing the algorithmic performance of control system, sub-systems, both for continuous and for sequential control. Algebraic methods are particularly appropriate because it is relatively easy to determine when two control system structures are algebraically equivalent. Some initial steps have been taken in manipulating these expressions, to produce new control system structures which have the same performance in the absence of failure, but which are more reliable. By studying the algorithmic structure of a control system (Vestkraft) it has also been possible to gain insight into the relationship between control system functional objectives. Extensive use of these techniques however, will depend on development of convenient automatic techniques for manipulating descriptions, since the amount of detail involved in the design of conventional control systems is very large.

The development to date provide the basis for the study of a complete practical control system. This in turn should provide the basis for determining how the functions of a control system can best be distributed among the different hardware components, making the best use of modern developments. It should also provide a basis for connecting the developments in control philosophy and technique, with the practical constraints of industrial application.

The work is at an early stage in achieving its goals. More experience is required in applying the techniques to large working systems. Already, however, it is apparent that there are many features in real control system structure which have so far received no theoretical treatment.

Current work is devoted to applying the descriptive techniques to larger parts of the Vestkraft control system, and to improving techniques for partitioning the control system. The prime objective here is to reduce the dependence of the control system on just a few components.

RELIABILITY

Current reliability techniques applied in technical fields may roughly be divided into studies to establish general characteristics (figures-of-merit) for defined systems and more situation-oriented studies which determine the probabilities of unsuccessful operation in specific situations.

Situation-oriented failure models are necessary in connection with for instance accident analyses where the performance of involved protection systems has to be assessed. In the part of the assessment that concerns investigations of system unreliability it is necessary to include all significant factors that at any time may affect the reliability. This means that besides failure of components such factors as repair policy, maintenance schedules, test policy, and ability of failure discovery should be taken into account.

A situation-oriented failure model of a redundant protection system, an emergency core cooling system, was evaluated. The model, determining the probability of system failure when a demand exists, is a multi-phase model, i.e. unavailability up to the moment of demand as well as unreliability during operation over a crucial time interval are taken into account.

In the system considered most components are tested "frequently" during normal power operation. Some few components are only tested when a thorough proof testing of the total system is carried out during scheduled reactor shut-down. The influence of the test policy on the basic reliability characteristics of the system is found through a parameter variation.

The evaluated analytical model is based on a book-keeping of relevant system states as well as state changes and the times at which these occur, and it leads to what may be called an integral model. Normally, the use of an integral model does not impose serious restrictions upon failure rates and repair rates of the components, and cases of statistical dependence can be handled. Furthermore, it is possible to handle systems that are operated in several phases.

In connection with the model evaluation the cause/consequence diagram method (ref. 1) is used, i.e. a cause/consequence diagram for the system is developed to such a level that it may support the model evaluation by giving a detailed and logical problem formulation. The consequence diagram for the emergency core cooling system is shown in fig. 6.

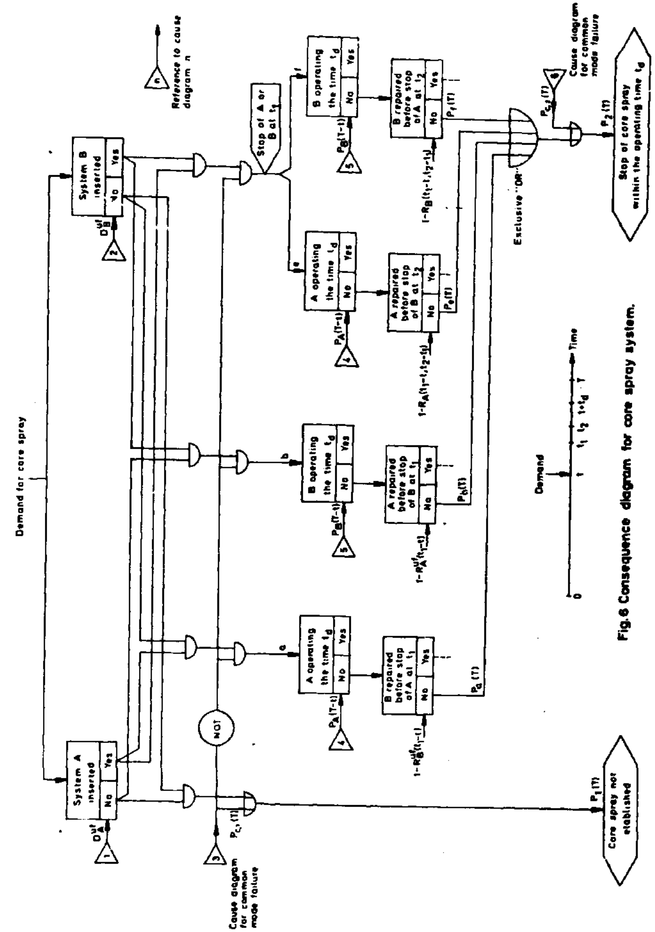

Fig.6 Consequence diagram for core spray system.

HYBRID COMPUTER

Introduction

The hybrid computer has been used for the simulation of a broad range of physical, chemical, and biological processes on an open shop basis. Typical among the subjects treated are adaptive control systems, optimization, pulse raiolyses, and superconductors. - The simulation of a pressurized-water reactor together with other large simulations showed a need for increased capacity of the analog as well as the digital computer. For this reason an extension was planned to take place over two years as a balanced increase of the analog and digital computers. The first phase of this plan is mentioned below. The changes made in digital hardware necessitated an extensive revision and new development of hybrid system software. The first part of this work is discussed below.

As a continuation of earlier work carried out in the field of optimization, three optimization strategies were compared (ref. 2). In connection with biological system simulation a study was made on the determination of kidney parameters by means of automatic curve fitting on patient data (ref. 3).

Hardware Extension

The hybrid computer EAI 680/PDP8/I was extended to include an FPP 12 floating point processor and an RK 8 812 k disc and now has 8 k core memory (figure 7).

The analog computer (figure 2) now has 167 operational amplifiers, 30 of which are integrators.

The FPP 12 extension typically increases the speed of floating point calculations to be 20 to 80 times the speed obtained by means of PDP8/I alone. The RK8 extension makes it possible to use the FORTRAN IV programming language.

Software Development

The basic software is the OS/8 monitor system combined with the RTPS FORTRAN IV system. A set of functions for the communication between the analog and the digital computer was developed. The functions are contained in one subroutine, which is called from a FORTRAN program by means of the statement

CALL ANI (A, B, C, D, E).

A is the function number, B, C, D, and E are input and output parameters.

A program SETAN is used for automatic potentiometer setting and static tests while another program READAN is used for automatic logging of analog element results. Both programs use magnetic tape as a storage medium and identical formats.

Fig. 7. Analog computer EAI 680 (left). Digital computer PDP 8I - FPP 12 (right).

RESEARCH INSTRUMENTATION

Pulse Radiolysis Instrumentation

Pulse radiolysis can be monitored by measuring the time variation in transmission of monochromatic light through the sample after irradiation with electron pulses. This variation reflects physical and chemical reactions e.g. between free radicals and excited molecules.

As a light source we use a 450-watt xenon lamp with a 30-ampere regulated power supply. A pulsed power supply can deliver up to 180 amp. extra during approx. 1 msec, and thus increase the light output up to 30 times (ref. 4). The xenon lamp is automatically ignited when the power is switched on.

After the light from the xenon lamp has passed the cell containing the irradiated sample, it passes a monochromator, and the light output from the output slit is measured with a photomultipliertube.We use two different photomultiplier set-ups. One is optimized with respect to a small time constant. With the other we can shoose the operating point that gives the best signal to noise ratio in a given situation.

Fast photomultipliers with rise times of less than 1 nsec have a focusing dynode geometry that makes the amplification very sensitive to variation in dynode voltage. By the exclusive use of zener diodes in the dynode chain we obtained a circuit with linear response during the light pulse and with fast recovery from overloading due to the strong Cerenkov radiation during the electron pulse. A drawback with this circuit is that sometimes it is necessary to reduce the light intensity to avoid overloading of the photomultiplier with a reduced signal to noise ratio as a result. For measurements where we do not need the fast response, we therefore use a photomultiplier whose dynodes are unfocused. It is not as sensitive to variation in supply voltage, and we can use resistors in the dynode chain. Thereby it is possible to change the amplification by changing the high-voltage supply and choose an amplification which together with the other measurement conditions gives the best signal to noise ratio. This photomultiplier is coupled to a broadband operational amplifier. The overall rise time is approx. 200 nsec. In front of the photomultiplier is placed a light-emitting diode to which current is supplied by a function generator. With this arrangement can we simulate measurement signals with rise times of 30 nsec and exponential decays with half-times of 100 nsec or 1 msec for test of the detector circuits and especially of the following recording and computer equipment.

Fast reaction kinetics with time constants of less than 1 μsec is recorded

Eksempel på kurve- og tabeludskrift
Signal fra lyadiode

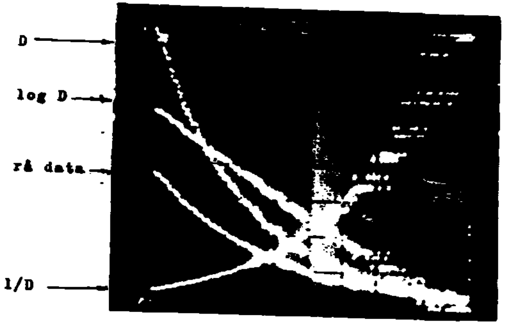

Fig. 8: Pulse Radiolysis, CRT - and printer readout, signal from light emitting diode.

```
PRESS READ
SET SWITCHES
N1, N2, N3
    70    101    101
T1, T2, T3
    16    16    16

IDOT=0
IDOT=0
IDOT=0
N?
1
256.
.05
256.
G?
1
2.
1=D,2=1/D,3=LOGD,4=LOGDU
1
SCF=        .361E 01
N?

G?

1=D,2=1/D,3=LOGD,4=LOGDU
2
SCF=        .139E-01
N?

G?

1=D,2=1/D,3=LOGD,4=LOGDU
3
SCF=        .538E 00
N?

G?

1=D,2=1/D,3=LOGD,4=LOGDU
1
    .213E-03    .271E 00    .248E 00    .224  00    .218  00
    .202E 00    .184E 00    .170E 00    .164E 00    .151  00
    .141E 00    .132E 00    .126E 00    .118E 00    .000  00


    .113E 00    .105E 00    .101E 00    .910E-01    .920 -01
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    .176E-01    .221E-01    .150E-01    .150E-01    .114 -01
    .176E-01    .114E-01    .141E-01    .796E-02    .560 -01
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with an oscilloscope equipped with a camera. Slower kinetics is recorded with a sampling and analog to digital conversion system described in ref. 5. This system is now connected to a PDP 8e computer, permitting calculation on site of the parameters of interest for the experiment. Measured and calculated curves are shown on a CRT display.

Transfer of data form the sampling system to the computer takes place via the teletype interface circuits with a speed of 880 bauds. The computer is interfaced with a storage scope, so that various curves can be compared. An XY-recorder may be used instead of the storage scope. A teletype is used for communication with the calculating program and for output of the results as tables.

Density, D, of the irradiated sample is calculated from the formula:

$$D = \log \frac{I_o}{I_o - I_s},$$

where I_o is the transmitted light before irradiation, and I_s is the reduction of the light after irradiation.

Furthermore the program can calculate $1/D$, $\log D$, and $\log(D_\infty - D)$. In the calculations corrections and constants are used which are either measured or read in via the teletype.

The program is written in FORTRAN and uses besides the teletype also the computer switch register for the operators' control. This gives relatively great flexibility in the use of the program which occupies the whole 4K memory of the computer.

Tube Inspection System

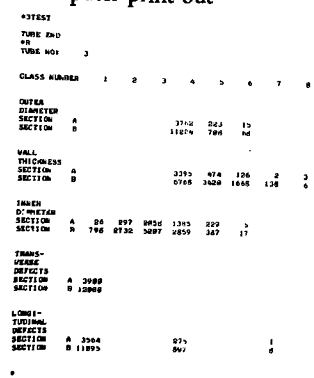
The metallurgy department is developing a non-destructive tube inspection system for measuring wall thickness, outer and inner diameter, and longitudinal and transverse defects. Participants in the project is The DAEC Risø, The Danish Welding Institute, and The Danish Research Centre for Applied Electronics (EC).

The Electronics Department participates as a link to the EC, which has made the software for the computer and developed a signal transformer that transfers the electrical signals to and from the rotating transducer head. Additionally the Electronics Department has built up the data handling system and the control system for tube movement and transducer head rotation.

The results of the measurements are printed out by the computer as shown in fig. 11 and may be divided into 16 groups, each corresponding to a certain part of the tube. The results from the 16 parts of the tube can be

Fig. 9. Tube Inspection System

Fig. 10



Computer print-out

*3TEST

TUBE END
*R
TUBE NO: 3

CLASS NUMBER		1	2	3	4	5	6	7	8
OUTER DIAMETER SECTION	A				3762	223	15		
SECTION	B				11224	708	[illegible]		
WALL THICKNESS SECTION	A				3395	474	126	2	3
SECTION	B				6768	3420	1668	138	6
INNER DIAMETER SECTION	A	26	297	2456	1385	229	5		
SECTION	B	796	2732	5207	2859	347	17		
TRANS-VERSE DEFECTS SECTION	A	3900							
SECTION	B	12089							
LONGI-TUDINAL DEFECTS SECTION	A	3564			275			1	
SECTION	B	11895			847			8	

Fig. 11

combined in the print-out. As shown here section A corresponds to $\frac{2}{16}$ of one end of the tube + $\frac{2}{16}$ of the other end. Section B corresponds to the rest of the tube. The figure in class 4 can be the number of measurements, where the diameter is the nominal diameter $\pm$ 15 µm, and the figure in class 5 is the number of measurements between nominal diameter + 15 µm and nominal diameter + 50 µm. The definitions of the classes is specified for the computer by means of the teletype or the high-speed reader before the test.

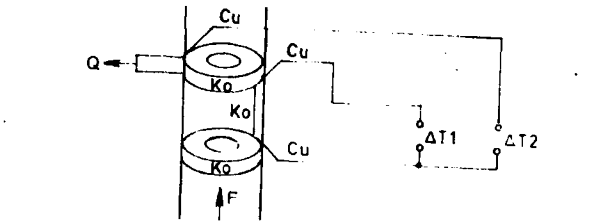
The equipment worked satisfactorily at the Nuclex exhibition and is of great commercial interest.

Thermodynamic Flow Meter

The thermodynamic flow meter is based on a principle developed by N.E. Kaiser (pat. app. for).

The principle, which can be used for both fluids and gases, was developed especially for blood flow measurements. The transducer is not destructive to the blood and is so inexpensive that it can be thrown away after use.

The transducer (fig.12) consists of 2 rings of constantan connected by a constantan wire placed in a flow tube. One of the rings is cooled (or heated) and the differential temperatures T1 and T2 are measured. The system of rings and wire of constantan in connection with copper wires makes up *differential* coupled thermocouples. Such a system can be used for flow measurements as $\frac{T2}{T1}$ is a function of flow and inside certain limits independent of the heat flow Q. $\frac{T2}{T1}$ is computed by means of a circuit shown in fig. 13. The principle can be used for measuring small flows where differential pressures are prohibitive.



$\frac{\Delta T2}{\Delta T1}$ is a function of flow

Typical figures:

Low flow: $\frac{\Delta T2}{\Delta T1} = \frac{5.5\,°C}{1.5\,°C} = 3.7$

High flow: $\frac{\Delta T2}{\Delta T1} = \frac{3.5\,°C}{0.3\,°C} = 11.6$

Fig. 12. Transducer

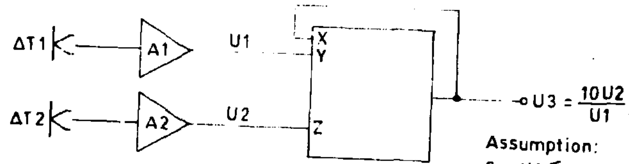


Fig. 13. Computing circuit

Assumption:
$0 < U1 \leqq 10V$
$|U2| \leqq 10V$
$U2 \leqq U1$

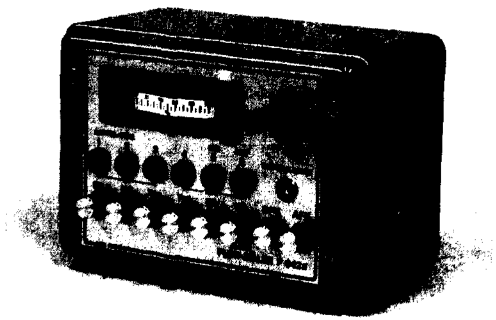


Fig. 14. Thermodynamic Flow Meter

LASER TECHNOLOGY

Introduction

The laser work of the Electronics Department is concentrated on the use of lasers in physical measurements.

Laser anemometry (i.e. measurement of liquid or gas velocities with laser light (an introduction to the work of the department can be found in refs. (7) and (8)) has been the dominating field. A series of basic investigations has been performed, partly as a foundation for the applied work ("two-phase flow" and "atmospheric anemometry").

A general investigation of light scattering from liquids and gases has been started as an extension of the laser anemometry work. In connection with low-level light detection photon counting is being investigated.

Basic Laser Anemometry

The Doppler effect - known long before the laser Doppler velocimeter - can physically be explained in several apparently different ways: The Doppler shift can be calculated by (1) considering the scattering as a collision between photons and particles, (2) using the Galilean (or Lorentz) transformation, or (3) considering the "Doppler frequency" as an interference phenomenon.

As far as we have been able to ascertain there is no evidence of any conflict between the three "models" in the quasi-stationary case (i.e. $v \ll c$) if the same assumptions are implied. This is not the case for the generally used fringe model, since it neglects heterodyning between beams scattered from different particles. If the model is based on the time-independent field distribution - and not on the intensity distribution - then the three models will give identical results.

A general two-dimensional, Fourier-optical model is established, extension to three dimensions is outlined for the general case and carried through for one specific case (9). It is shown how the various configurations (i.e. differential modes and reference beam modes) are incorporated in the model. The basic configuration is shown in fig. 15.

The influence of the size of the receiver aperture is emphasized by detailed calculations for configurations which are believed to be representative of the laser anemometer:

(a) a large receiver aperture, but no directly transmitted beams;

(b) a very small aperture, no directly transmitted beams;

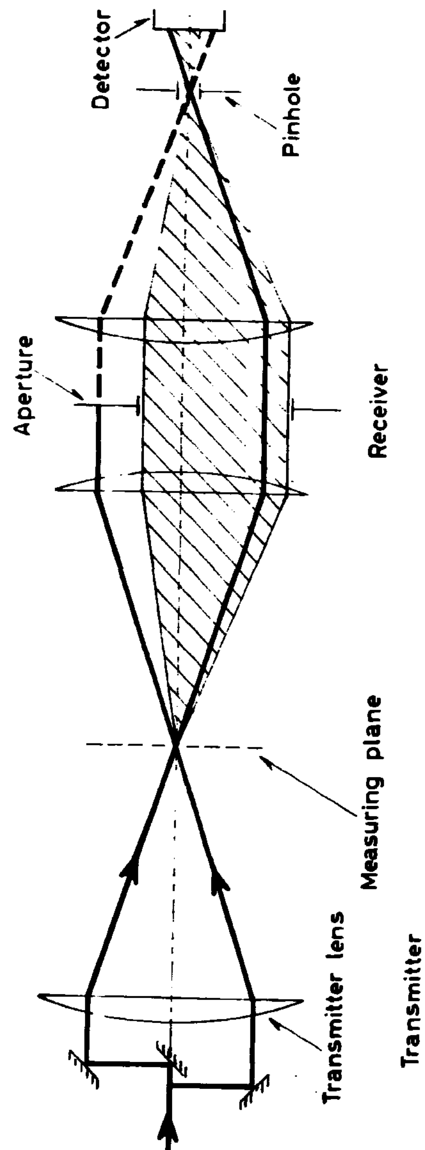


Fig. 15. Basic optical set-up. The aperture position and diameter are variable.

(c) a large receiver aperture, one directly transmitted beam within the aperture;

(d) a very small aperture, placed around the centre of one of the directly transmitted beams.

A large aperture is an aperture so large that heterodyning is only performed between beams scattered by the same particle, while a small aperture is an aperture so small that heterodyning is performed between all beams scattered from the measuring volume.

The signal to photo shot noise ratios were calculated, and they were found to be (the detailed calculations will be published in ref. 10):

(a) $\frac{S}{N} \sim \frac{1}{8\pi} \quad \frac{K}{e} \cdot \frac{A}{F^2} \; P_o(\frac{r_o}{\lambda F}) \; \frac{\langle \sigma^2 \rangle}{\langle \sigma \rangle} \cdot \frac{1}{v}$;

(b) $\frac{S}{N} \sim \frac{1}{8\pi} \; \frac{K}{e} \cdot \frac{A}{F^2} \; P_o(\frac{\lambda F}{r_o}) \langle \sigma \rangle \quad c' \; \frac{1}{v}$;

(c) $\frac{S}{N} \sim \frac{1}{8\pi} \; \frac{K}{e} \cdot \lambda^2 \quad P_o(\frac{r_o}{\lambda F}) \; \langle \sigma \rangle c' \; \frac{1}{v}$;

(d) $\frac{S}{N} \sim \frac{1}{8\pi} \; \frac{K}{e} \cdot \frac{A}{F^2} \; P_o(\frac{\lambda F}{r_o}) \; \langle \sigma \rangle \; c' \; \frac{1}{v}$;

where

$\langle \sigma \rangle$ is the average scattering cross section (m^2/sr),

r_o the unfocused beam diameter,

A receiver aperture area,

F focal length of the lenses in the set-up (fig. 15),

P_o transmitted optical power,

λ wavelength of the laser light,

K sensitivity of the detector (A/W),

e charge of the electron,

v velocity of the scattering particles (assumed to be the same for all particles)

c' is the number of particles pr. unit area (a two diamensional model is used).

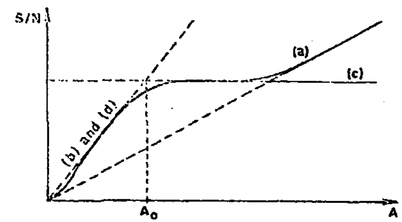


Fig. 16. Signal-to-photo-shot-noise ratio (power) versus aperture area. The dotted lines indicate the S/N sketched on the basis of the formulas given for cases (a), (b), (c) and (d), respectively. A_o is the area of the directly transmitted beam at the aperture.

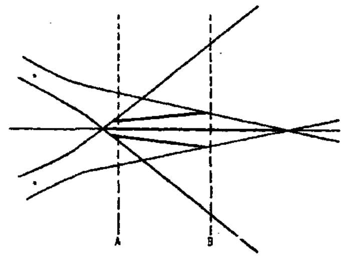


Fig. 17. Interference pattern for two intersecting gaussian beams.

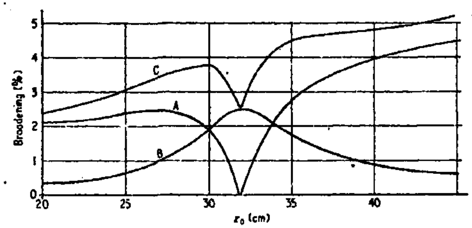


Fig. 18. Calculation of the broadening in an experimental set-up, plotted against the distance from the lens to the measuring volume: A, broadening caused by gradients between the interference planes; B, broadening caused by the finite transit time; C, total broadening.

Fig. 16 shows the S/N versus aperture diameter sketched on the basis of these formulas.

It can be concluded that the "differential" mode configuration will give a signal to photo shot noise ratio which is equal to, or better than, that obtained with an equivalent "reference beam" configuration. However, if the dark current noise and/or amplifier noise is playing a role (photodiode), then the reference beam configuration might be preferable. The maximum S/N will generally be independent of particle concentration, but not of the distribution of particle size.

Broadening in a laser-Doppler velocimeter is generally associated with the finite transit time of the scattering particles.

Another type of broadening is caused by the fact that the interference planes are not parallel within the measuring volume. We have studied this type of broadening, which generally cannot be neglected, and shown how it depends on the configuration of the set-up. (This work will be published in ref. 11).

In a set-up like the one shown in fig. 15 two beams intersect in the measuring volume. The intersecting beams will usually generate an interference pattern which in the case of plane waves consists of equidistant parallel planes. A beam of finite diameter cannot also be a plane wave, and that implies that the interference pattern will be somewhat different from that generated by plane waves, in fact it might look as is shown in fig. 17. We have shown that - to a first-order approximation - the interference planes will only be parallel if the beam waists (i.e. the minimum diameters) of the Gaussian beams coincide.

A computer program has been made which calculates the broadening due to finite transit time, interference plane gradients, and the sum of the two. Fig. 18 shows an example of such a calculation.

Remote Measurement of Wind Velocity by Laser Anemometry

A project aimed at remote measurement of wind velocity was started in 1972. The initial work covered a "feasibility" study. We especially looked at a system like the one shown in fig. 19. The aim is to measure the horisontal velocity with ground-based equipment. Our calculations show that it should be possible to obtain real time measurements at a range of up to 100 m. This is based on rather rough estimates of the required S/N and of the scattering properties of the natural aerosols.

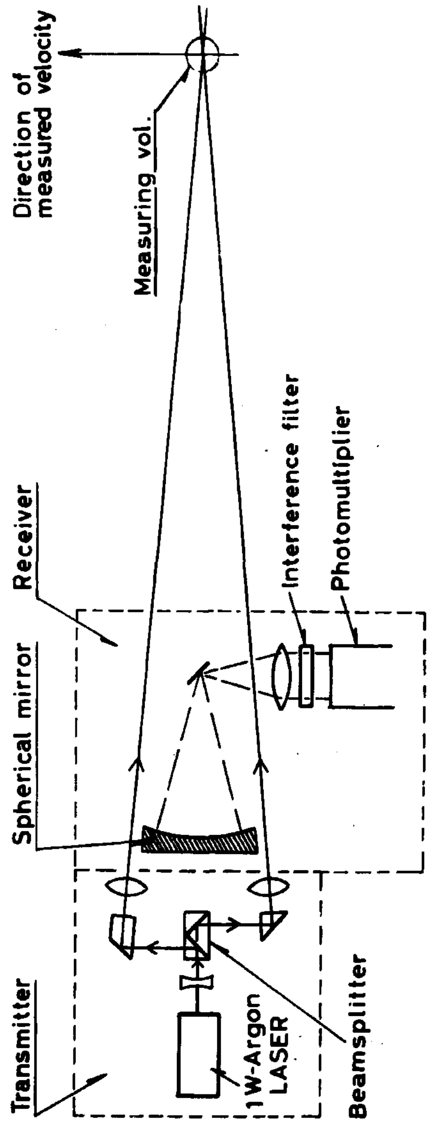


Fig. 19. Typical dimensions of the measuring volume: 0.5 cm x 50 cm, 0.5 cm in the direction of the measured velocity and 50 cm along the optical axis.

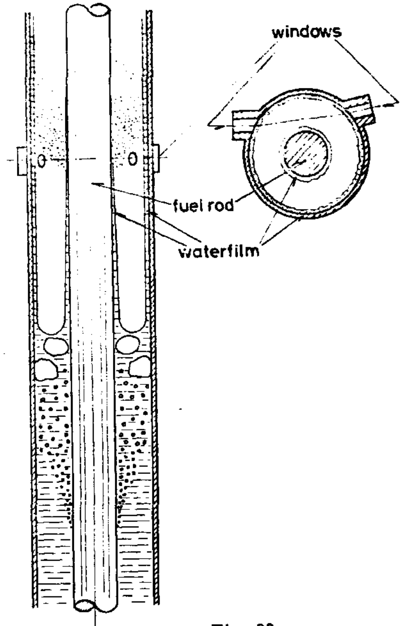


Fig. 20

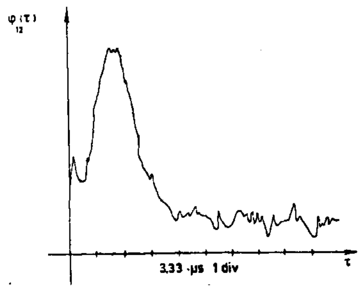


Fig. 21

A model of 1/10 scale was tested. The distance between the two beams was 10 cm and the diameter of the collecting mirror 10 cm. With a spectrum analyser as signal processor it was possible to get a signal with S/N>1 at a range of 10 m. A longer range, but with the same collecting solid angle, should not give any change in signal quality provided beam wandering due to random fluctuations of the refractive index of the atmosphere can be neglected and the stability of the system maintained.

We are at present constructing a large-scale set-up. Signal processing by other methods than simple spectral analysis is being considered, e.g. by tracking filter, multichannel correlation, and random sampling, but no decisive experiments or calculations have been made yet.

Two-Phase Flow Measurements Utilizing Laser/Correlation Techniques

Two-phase flow measurements were performed on a high pressure loop. The set-up used is based on the cross-correlation of the noise signals induced on two parallel laser beams by the flow (a short description of the method is given in ref. 8).

The configuration of the test section is shown in fig. 20. A typical cross -correlation function is shown in fig. 21. The curve gives at weighted time -of-flight spectrum for the disturbances passing the beams.

On the basis of the first series of experiments on a realistic loop the following preliminary conclusions can be made:

1. It is possible to obtain correlation curves of some sense.
2. It does not seem possible to measure the velocity of the inner water film with the present set-up.
3. More work has to be performed in order to get a better relation between the measured correlation curves and the velocity distribution of the particles (drops/bubbles) both in relation to space and particles.
4. It seems possible to make a velocity versus particle size spectrum by introducing appropriate filtering before the correlation is performed.
5. More resistant windows are needed. The inner surfaces of the presently used quartz windows can only retain their optical quality for approx. 4 hours when exposed to 70 bars and 280°C.

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